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RESEARCH MEMORANDUM

LOW-SPEED TESTS OF A FREE-TO-YAW MODEL IN TWO
WIND TUNNELS OF DIFFERENT TURBULENCE

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RESEARCH MEMORANDUM

LOW-SPEED TESTS OF A FREE-TO-YAW MODEL IN TWO
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SUMMARY

Tests have been made at low speeds in the Langley low-turbulence pressure tunnel which has a very low turbulence level and in the Langley stability tunnel which has a turbulence level approximately ten times as great in order to determine the extent of any resulting oscillations of a model mounted with freedom in yaw and in order to demonstrate the extent to which directional fluctuations in an air stream can be responsible for such oscillations. The results of these tests indicate that, for Mach numbers up to about 0.34, this model experiences no discernible self-sustaining directional oscillation other than that provided by response of the model to turbulence existing in the tunnel air stream. These data indicate the desirability of using an air stream of very low turbulence for investigations of snaking oscillations.

INTRODUCTION

Small-amplitude snaking oscillations of approximately 1° amplitude which are apparently undamped have been observed during flight tests of several high-speed airplanes. Oscillations of this type have been shown to result, in specific instances, from such causes as nonlinear damping characteristics, fuel sloshing (reference 1), or slack in control systems. It has also been shown that the rate of damping can be influenced by compressibility effects at Mach numbers approaching unity. (See references 2 and 3.) In addition to these causes which may be attributed to the airplane configuration itself, however, it has been known for some time that airplanes have a tendency to perform angular oscillations when traversing regions of turbulent air. Reference 4, for instance, shows some records of the angular motion of several airplanes flying in air having various degrees of unsteadiness. The analysis of reference 5 shows further that an airplane having a low rate of damping can respond to a random distribution of turbulence in such a way as to experience a very regular oscillation of nearly constant frequency.

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As an example of response to turbulence, reference 5 gives the case of a model mounted with freedom in yaw in the air stream of the Langley stability wind tunnel. Calculations that are given indicate fair agreement with the experimental result. There exists the possibility, however, that some agency other than the turbulence is a contributory factor, for example, the lag in growth of the boundary layer on the surface of the fuselage. In order to determine the extent of any undamped snaking oscillations and to demonstrate the extent to which turbulence in an air stream can be responsible for such oscillations, therefore tests on a model free to oscillate in yaw have been made in the Langley low-turbulence pressure tunnel which has a very low turbulence level and in the Langley stability tunnel which has a turbulence level approximately ten times as great.

SYMBOLS

The coefficients employed in this paper are in standard NACA form and are based on the span and area of the normal model wing which was not used for these particular tests.

C_n yawing-moment coefficient (N/qS)

$C_{n\beta} = \frac{\partial C_n}{\partial \beta}$, radian measure

$C_{n_r} = \frac{\partial C_n}{\partial \frac{rb}{2V}}$, radian measure

I_z moment of inertia about z axes

ψ azimuth angle of airplane, degrees

β angle of sideslip of airplane, degrees

σ_0 amplitude of oscillation in air-stream direction, degrees

ψ_0 amplitude of oscillation in model heading, degrees

S wing area

b wing span

N yawing moment about z axis

$\frac{rb}{2V}$	yawing-velocity parameter, radian measure
r	yawing angular velocity about z axis, radian measure
V	free-stream velocity
q	dynamic pressure $\left(\frac{\rho V^2}{2}\right)$
ρ	mass density of air
R	Reynolds number $(\rho V l / \mu)$
M	Mach number
l	fuselage length
μ	viscosity of air
k	spring constant of flexure plates in mounting system, 8.2 foot-pounds per radian

MODEL AND TEST METHOD

A sketch of the model and support arrangement is shown in figure 1. A 0.1-scale model of the Bell X-1 research airplane fuselage and tail assembly was mounted on a yaw stand from the ceiling of each tunnel. The model was supported on flexure plates which permitted it to rotate about its yaw axis with a minimum of friction but restrained it in all other directions. Pertinent mass and aerodynamic characteristics of the model are also listed on figure 1. The aerodynamic derivatives were determined from the time history of the model motion following an abrupt yawing disturbance. These aerodynamic derivatives are averages of values obtained from the tests in the Langley low-turbulence pressure tunnel at dynamic pressures from 40 to 150 pounds per square foot. The model motion damped to a very small amplitude in this facility and therefore provided a very accurate determination of these derivatives. Records of the free-yawing oscillations of the model were made for dynamic pressures ranging from 4 to 65 pounds per square foot in both tunnels and up to 175 pounds per square foot in the low-turbulence pressure tunnel. Measurements of the fluctuation in air-stream direction were made in both tunnels by use of an electronic pitot which was about 1 inch in diameter and about 1 foot long. Figure 2 gives sample records of the fluctuations in both facilities for several dynamic pressures. Records are not included for the low-turbulence pressure tunnel for the

low dynamic pressures because the fluctuations in pressure were too small to record satisfactorily. An examination of the records indicates that the scale of the turbulence is fairly large relative to the size of the model tested. The large peaks in the records are about $1\frac{1}{2}$ feet apart at all dynamic pressures if the time scale is interpreted as distance by use of the forward velocity. The amplitudes of the directional fluctuations were about 0.1° in the low-turbulence pressure tunnel and about 1° in the stability tunnel. All tests were made in air at atmospheric pressure and covered a range of Reynolds numbers (based on fuselage length) from 1.5×10^6 to 7.6×10^6 and a Mach number from 0.05 to 0.34 for dynamic pressure from 4 to 175 pounds per square foot.

RESULTS AND DISCUSSION

Records of the model yawing oscillations observed in the two tunnels at three different values of dynamic pressure are shown in figure 3. For each dynamic pressure, the model oscillates at nearly constant frequency and amplitude with only occasional deviations from this regular motion. The frequency of the observed model oscillations becomes higher for higher dynamic pressure, and in each case is approximately equal to the natural frequency of the model and flexure plates. The results showed that the amplitude of the oscillations in the stability tunnel was about 1° or approximately equal to the amplitude of the snaking oscillations observed during flight tests of some high-speed airplanes. The amplitudes observed in the Langley low-turbulence pressure tunnel, on the other hand, were for all practical purposes negligible (approx. 0.1°).

Computations were made, following the procedure described in reference 5, of the model motion which should result from a typical sample of the air-stream fluctuations observed in the stability tunnel at one dynamic pressure. Although the model motion and air-stream directional fluctuation measurements were not made simultaneously, each is considered typical of the variations to be encountered at that dynamic pressure. The results of these computations are shown in figure 4 along with the air-stream fluctuation considered for the computations and the model motion observed at the same dynamic pressure. There is, of course, no possibility of a point-by-point comparison between the computed and observed motions, but the similarity between the two motions is obvious. In spite of the irregular variation of stream direction, both the calculated and observed model response have a frequency equal to the natural frequency of the model and relatively small variations in amplitude with time. The computed response shows an amplitude somewhat higher than the experimental result. The analysis

of reference 5 shows that the type of response indicated by these results is precisely that which can be obtained from a model having sharply peaked frequency-response characteristics similar to those of the present model (see fig. 5) when subjected to a random variation in stream direction.

The lack of any significant oscillation of the model in the smooth air stream of the low-turbulence pressure tunnel and the approximate correspondence between the calculated and observed motions in the stability tunnel indicate that the sole contribution to the model motion is provided by the air-stream fluctuations.

Records of the free motion of the model used in these tests following a large displacement in yaw showed no decrease in damping as the Mach number was increased within the range investigated. Inasmuch as references 2 and 3 show that the compressibility effects on the lift of oscillating wings are such as to cause a decrease in the rate of damping, it is possible that self-sustaining lateral oscillations may be a characteristic of this configuration at higher speeds than those of the present tests.

The fact that the amplitudes of the model motion in response to turbulence can be as large as the amplitude of the snaking motion characteristic of some high-speed airplanes indicates that a very smooth air stream would be desirable for studying snaking oscillations. A turbulence level comparable to that of the low-turbulence tunnel, several hundredths of a percent, should be satisfactory. Percent turbulence is defined as 100 times the ratio of the root-mean-square velocity fluctuation to the free-stream velocity.

CONCLUSIONS

The results of observations of the free yawing motion of a model in two wind tunnels having different degrees of turbulence indicated the following conclusions.

- (1) No agency other than the turbulence in the air streams contributed noticeably to the free yawing motion of the model up to a Mach number of 0.34.

(2) Investigations of snaking oscillations should be made in an air stream of as low turbulence as possible.

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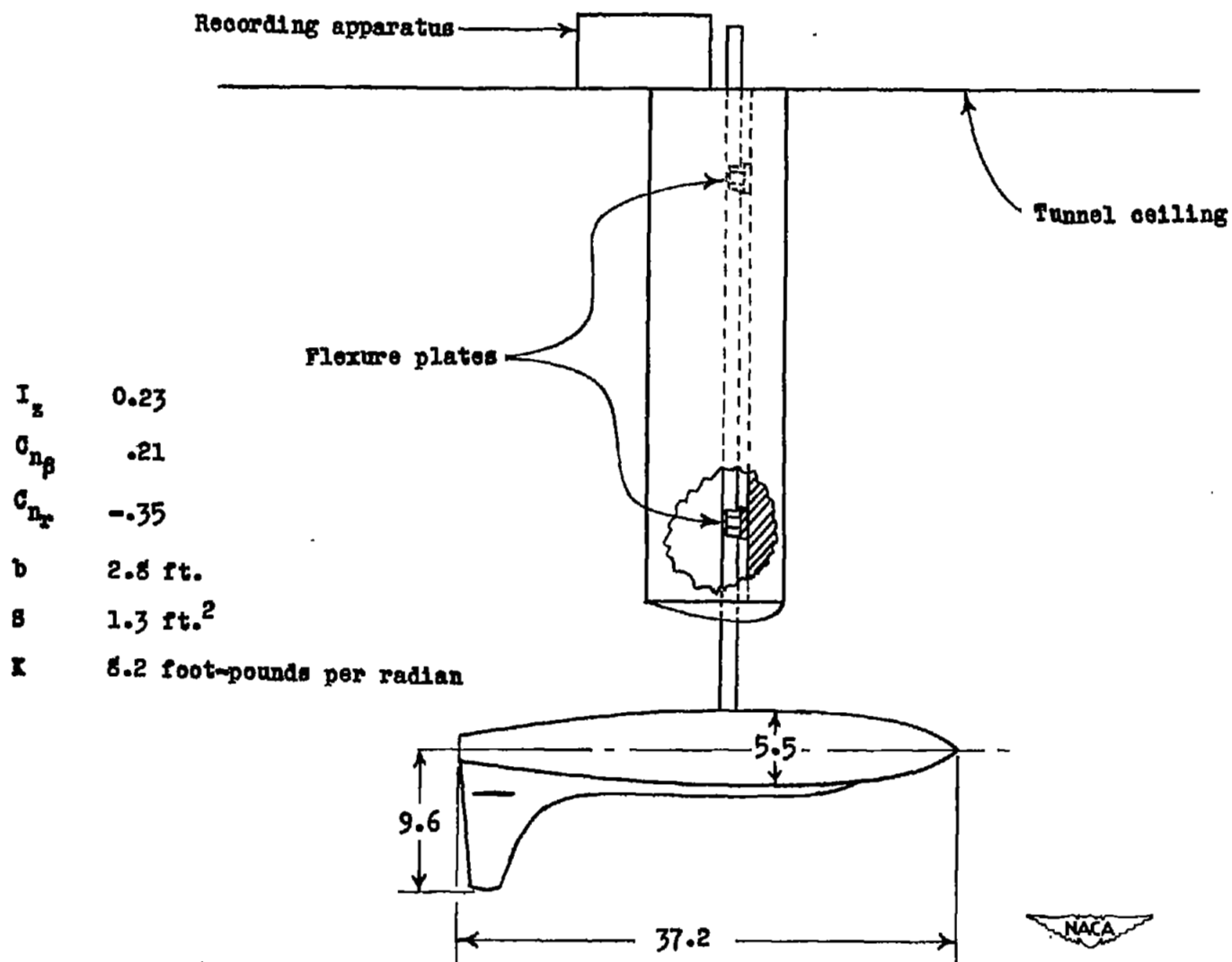
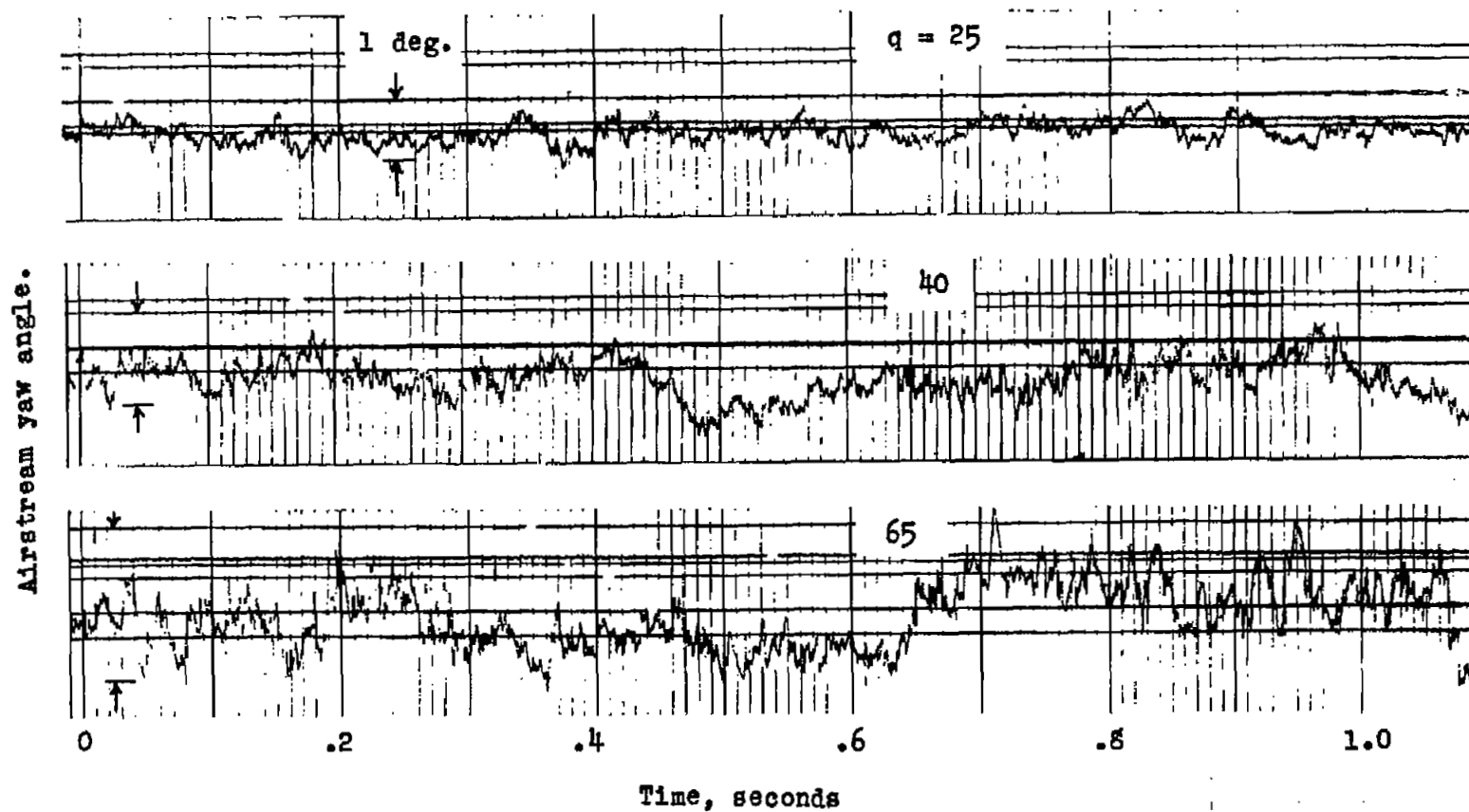
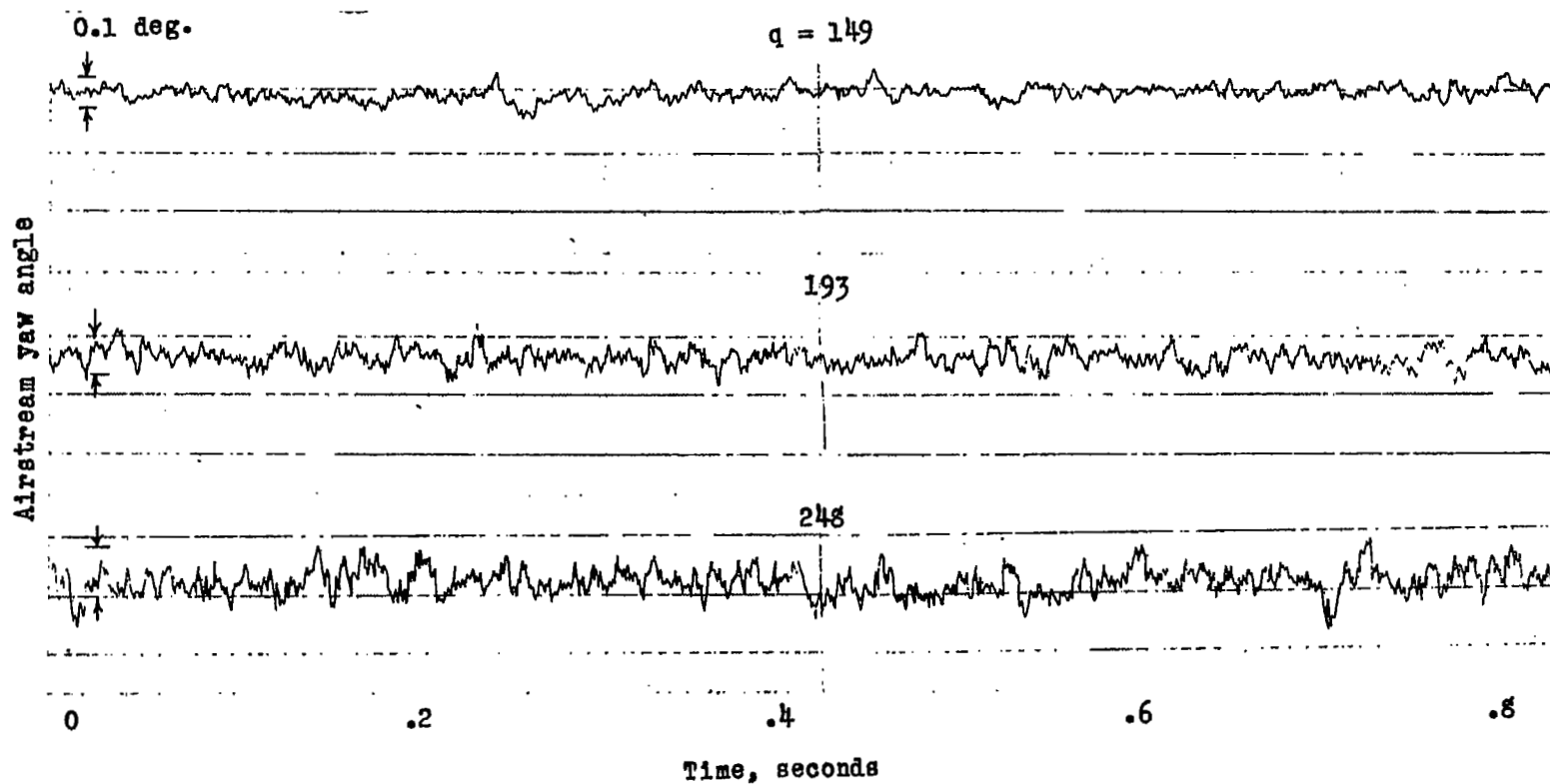


Figure 1.- Sketch of model and support arrangement used for tests in both wind tunnels. (All dimensions are given in inches.)



(a) Stability tunnel.

Figure 2.- Records of air-stream directional fluctuation in the Langley stability tunnel and in the Langley low-turbulence pressure tunnel.



(b) Low-turbulence pressure tunnel.



Figure 2.- Concluded.

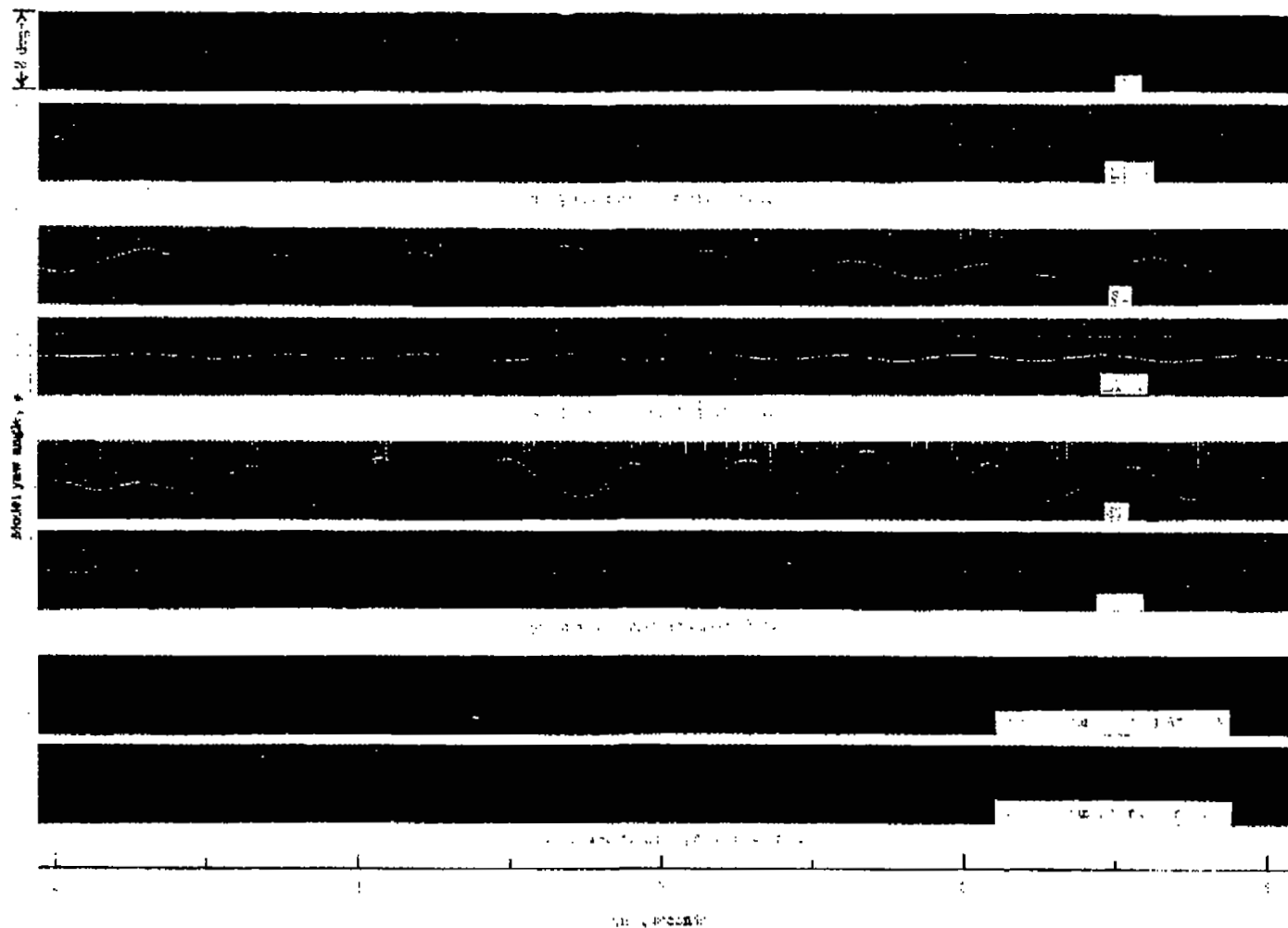
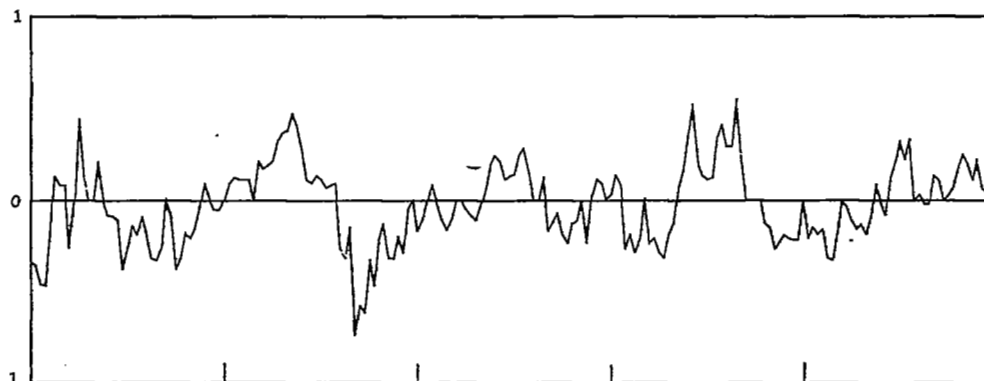
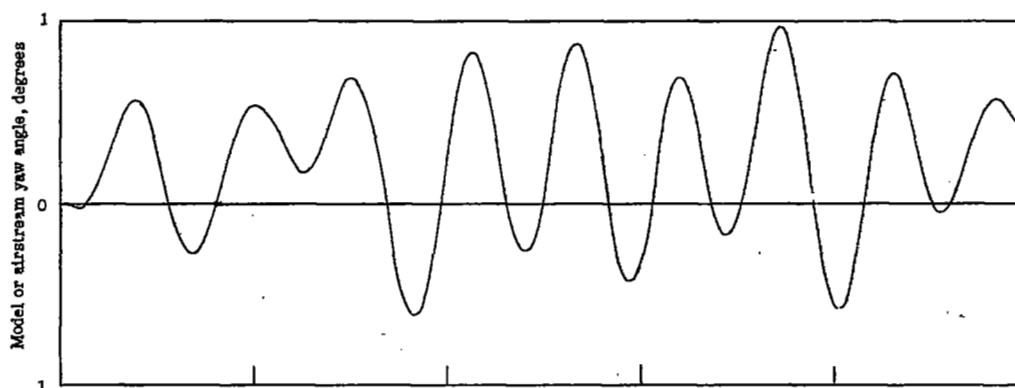


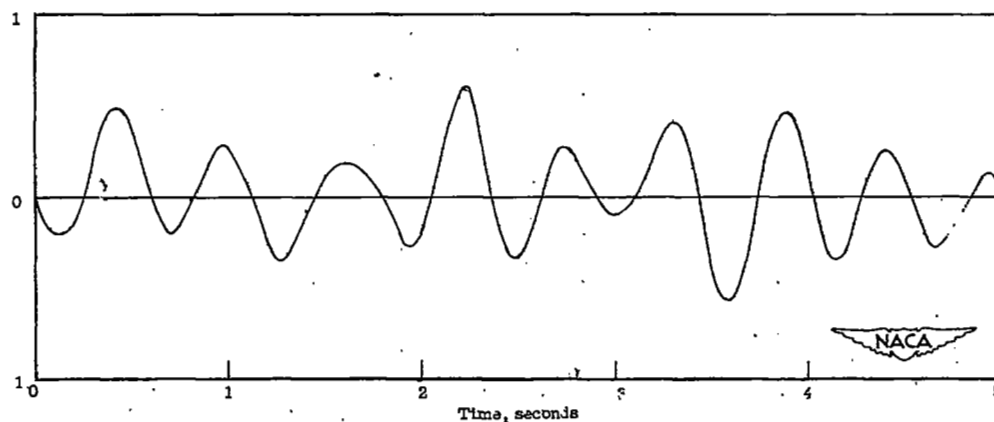
Figure 3.- Typical samples of yawing oscillations of model measured at various dynamic pressures in the low-turbulence pressure tunnel (LPT) and in the stability tunnel (ST).



(a) Air-stream direction fluctuation.



(b) Calculated model motion.



(c) Observed model motion.

Figure 4.- Comparison of typical model yawing motions obtained from calculations and from experiment. Dynamic pressure, 25 pounds per square foot.

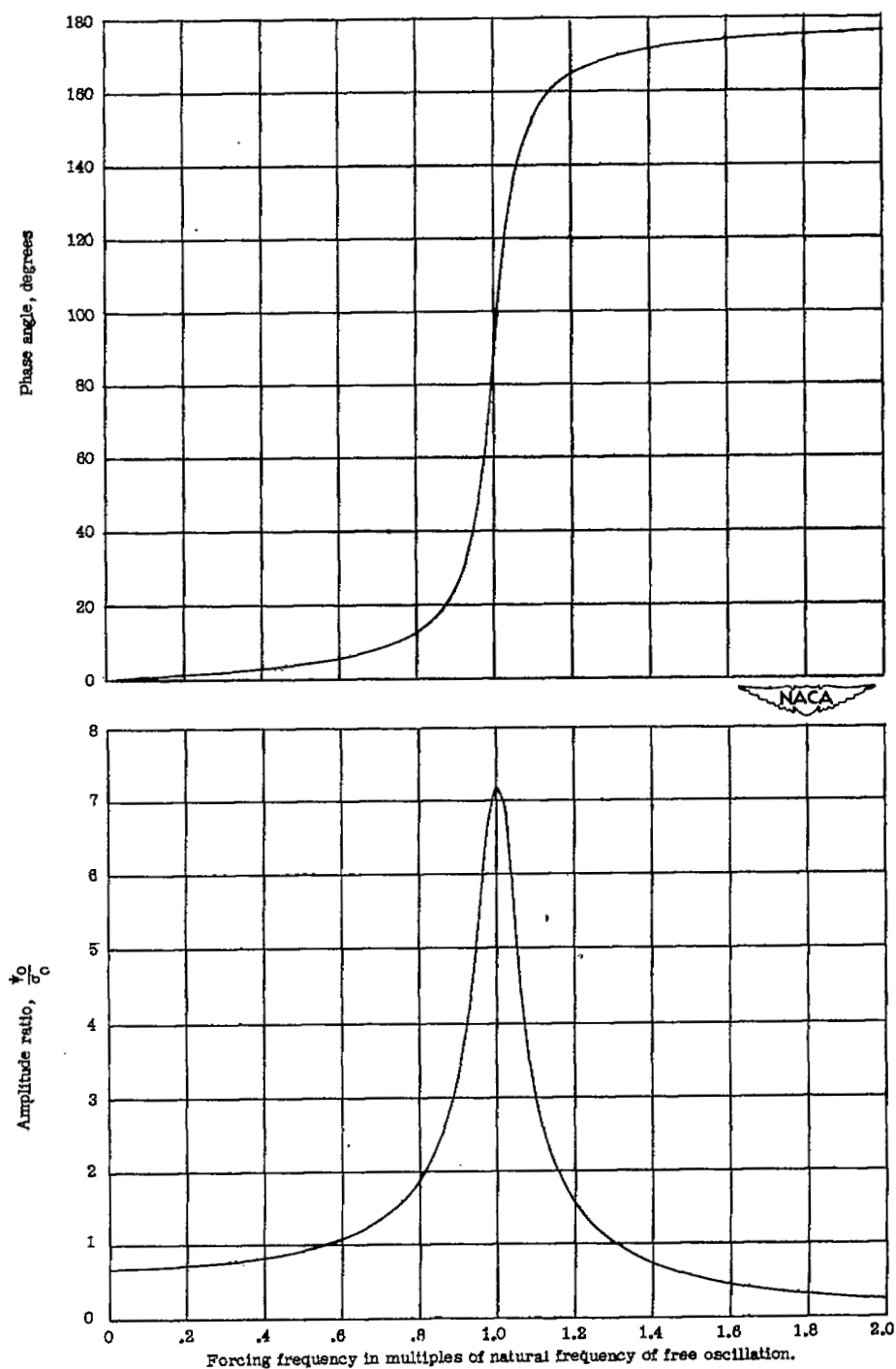


Figure 5.- Computed response of model to sinusoidal air-stream directional fluctuation of unit amplitude. Dynamic pressure, 25 pounds per square foot; $k = 8.2$ foot-pounds per radian.

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